GPM for Hydropower Reservoir Operation in Africa

Mekonnen Gebremichael

The 2019 PMM Science Team Meeting, November 4-8, 2019, Indianapolis, IN

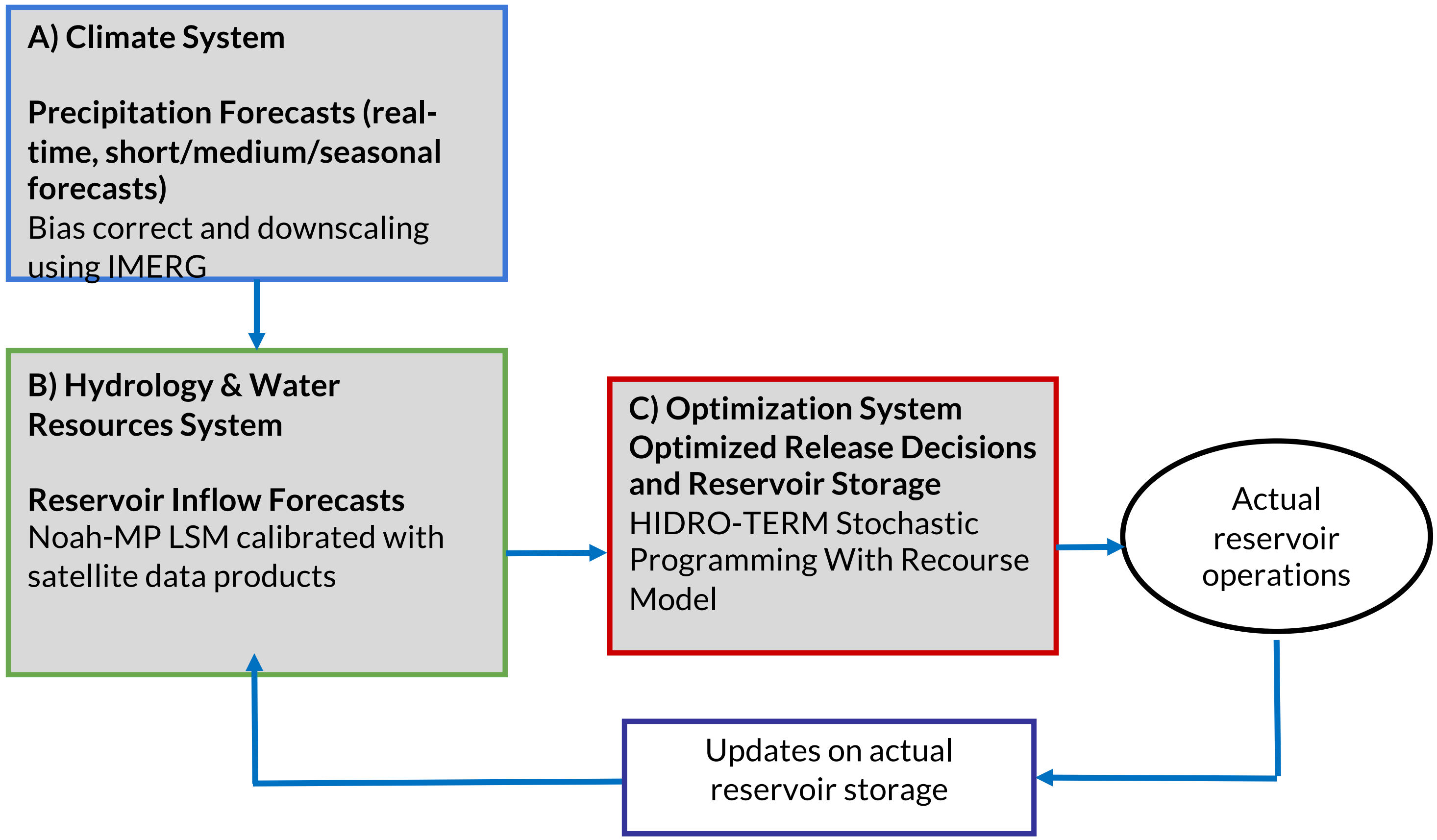
UCLA Engineering
Civil and Environmental Engineering
Engineering Sustainable Infrastructure for the Future

The Problem

- Only a quarter of the population in sub-Saharan Africa has access to electricity
- Reservoir-based water management systems are used in sub-saharan Africa for energy generation. Power generation efficiency of these reservoirs is very low (~ 30%) of design capacity
- Reservoir operators do not use forecasts and optimization tools for reservoir management. The potential for improving the performance of hydropower dams, through a decision support system that uses forecast and optimization tools, is very high
- Key variables for optimal reservoir planning and operation: available storage capacity, expected inflow from current and future weather, expected demand

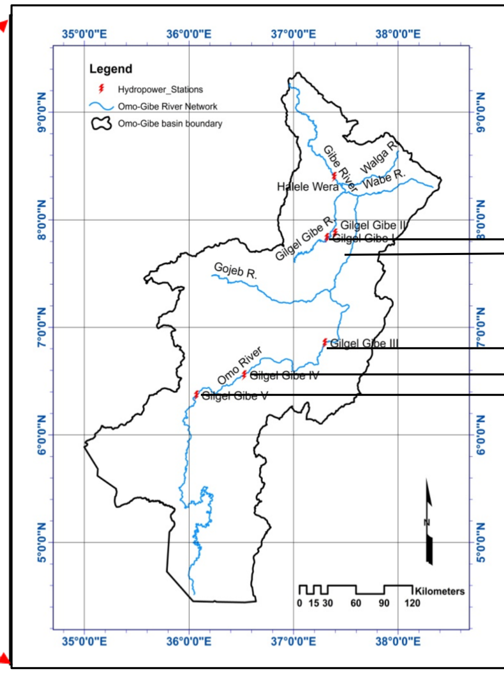
Objective

To develop a new GPM-based Hydropower Reservoir Operation Framework



Study Area and Time Period

East African Power Pool



Omo-Gibe River Basin

Gibe I (2004)
Installed Capacity - 210MW
Max Storage - 840 Mm3

Gibe II (2010)
Installed Capacity - 420 MW
Max Storage - 0.15 Mm3

Gibe III (2015)
Installed Capacity - 1870 MW
Max Storage - 13700 Mm3

Gibe IV (Planned)
Installed Capacity - 1450 MW

Gibe V (Planned)
Installed Capacity - 600 MW

Planning Horizon - 8 months
Calibration Period - 200401 to 200412
Study Period - 200502 to 200509
Validation Period - 200501 to 200512

Methodology

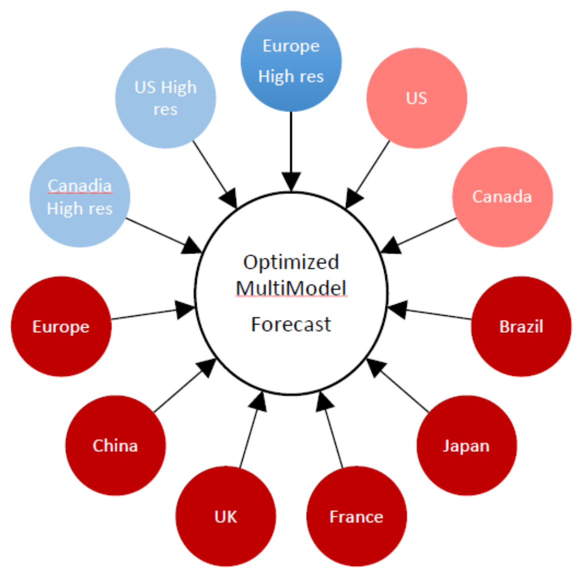
- **Task 1: Identify and develop a methodology to seasmlessly utilize <u>precipitation forecasts</u> as input into the Noah-MP hydrologic model for hydrologic forecasting**

Datasets

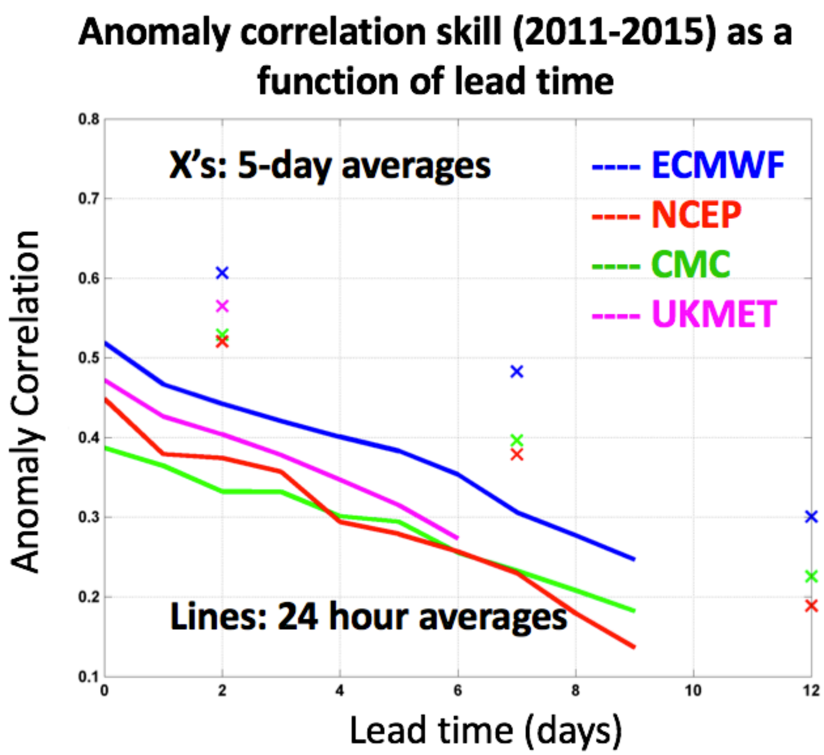
- Near-real-time and Reference Data: IMERG
- Short to Medium Range Forecasts
- Sub-seasonal to seasonal Forecasts
- Seasonal Forecasts

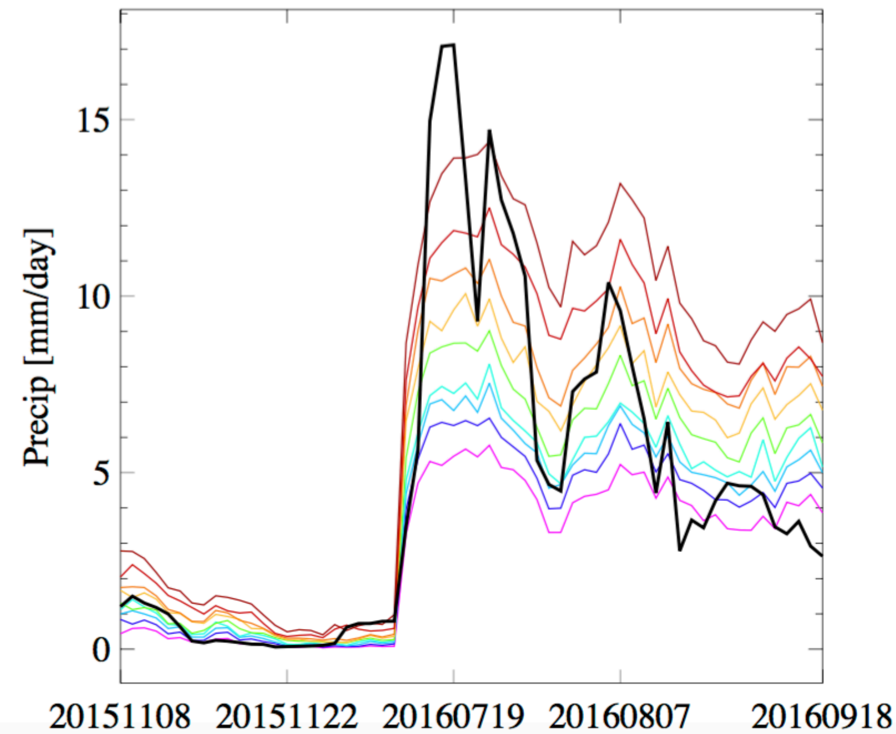
Tasks

- Identify skills in forecasts
- Enhance skills using physical indicators (e.g., MJO)
- Ensemble model forecast
- Bias correction and downscaling



Ongoing Results: Skills of short-range forecasts

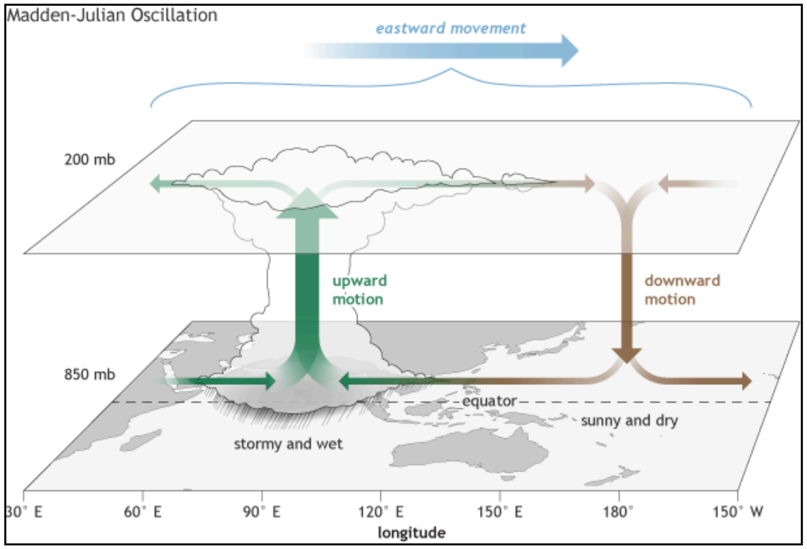




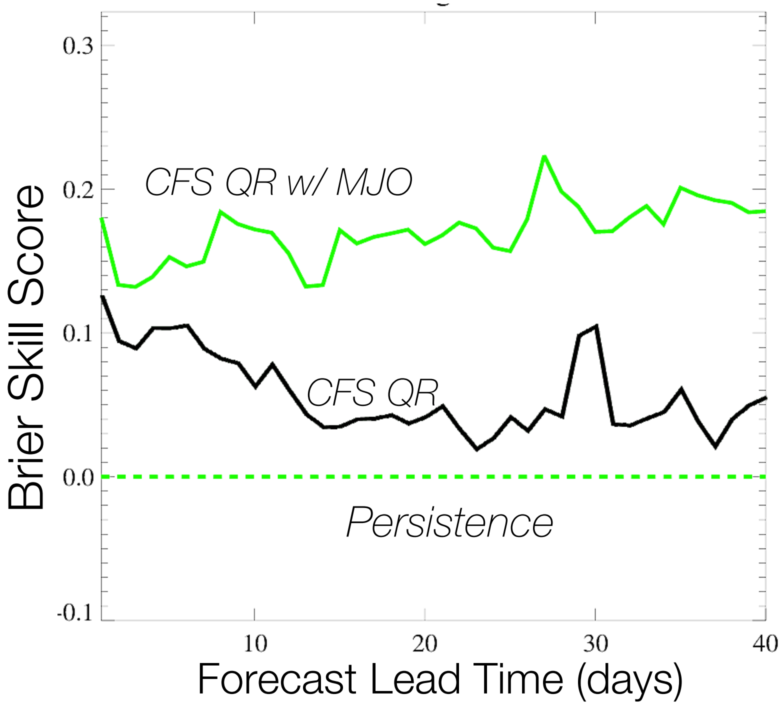
Calibrated forecast of 5-day rainfall using NCEP, ECMWF, CMC, and UKMET models.

Ongoing Results: Calibration of 15-day to 45-day forecasts

Madden-Julien Oscillation (MJO)



Omo-Gibe 5-day Accumulations



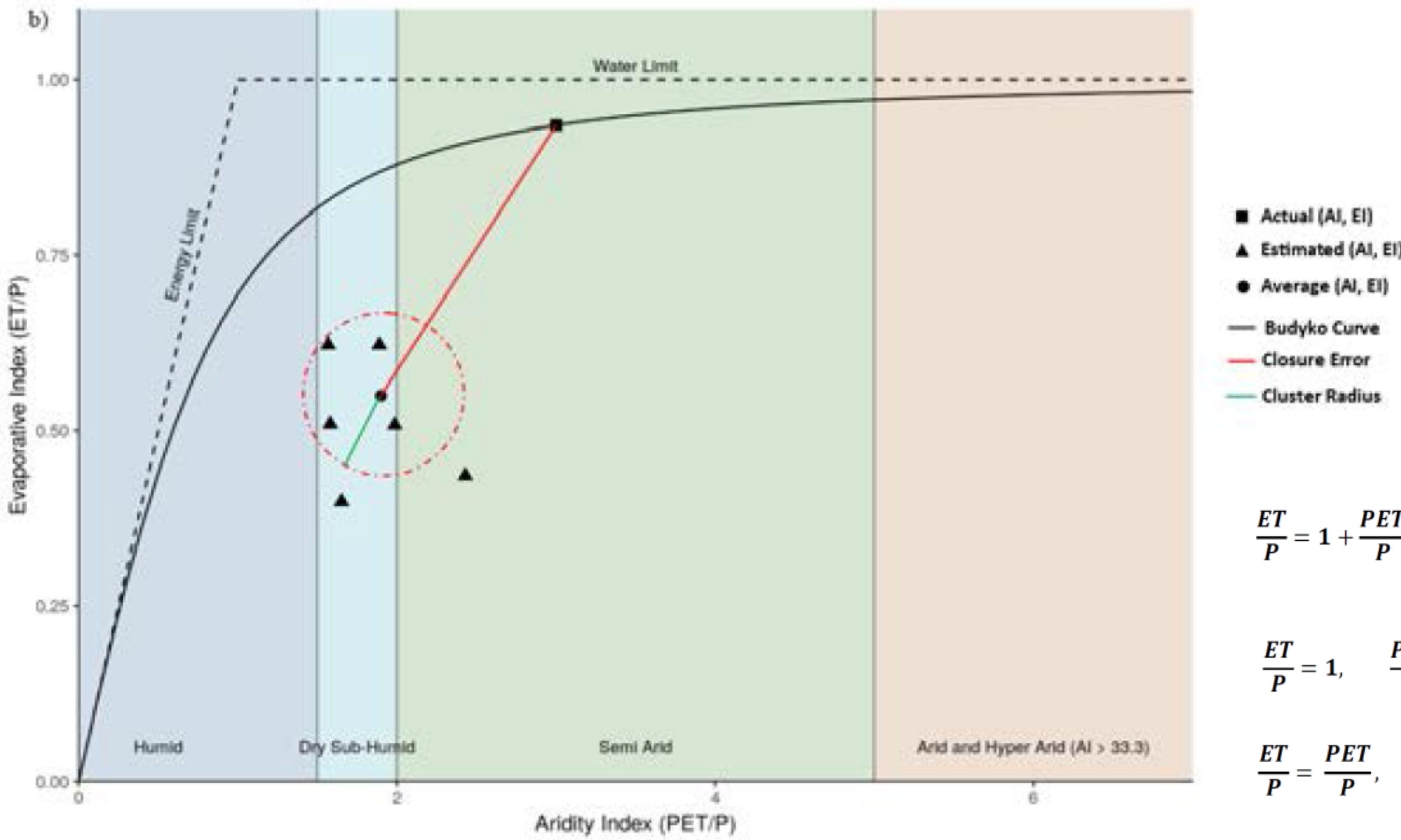
Methodology

- **Task 2: Calibrate the Noah - MP model using satellite evapotranspiration and soil moisture products as well as in - situ streamflow data for forecasting reservoir inflows driven by near real - time and sub - seasonal precipitation forecasts**

Tasks

- Develop a new methodology to identify suitable satellite product for model calibration

The Budyko Curve

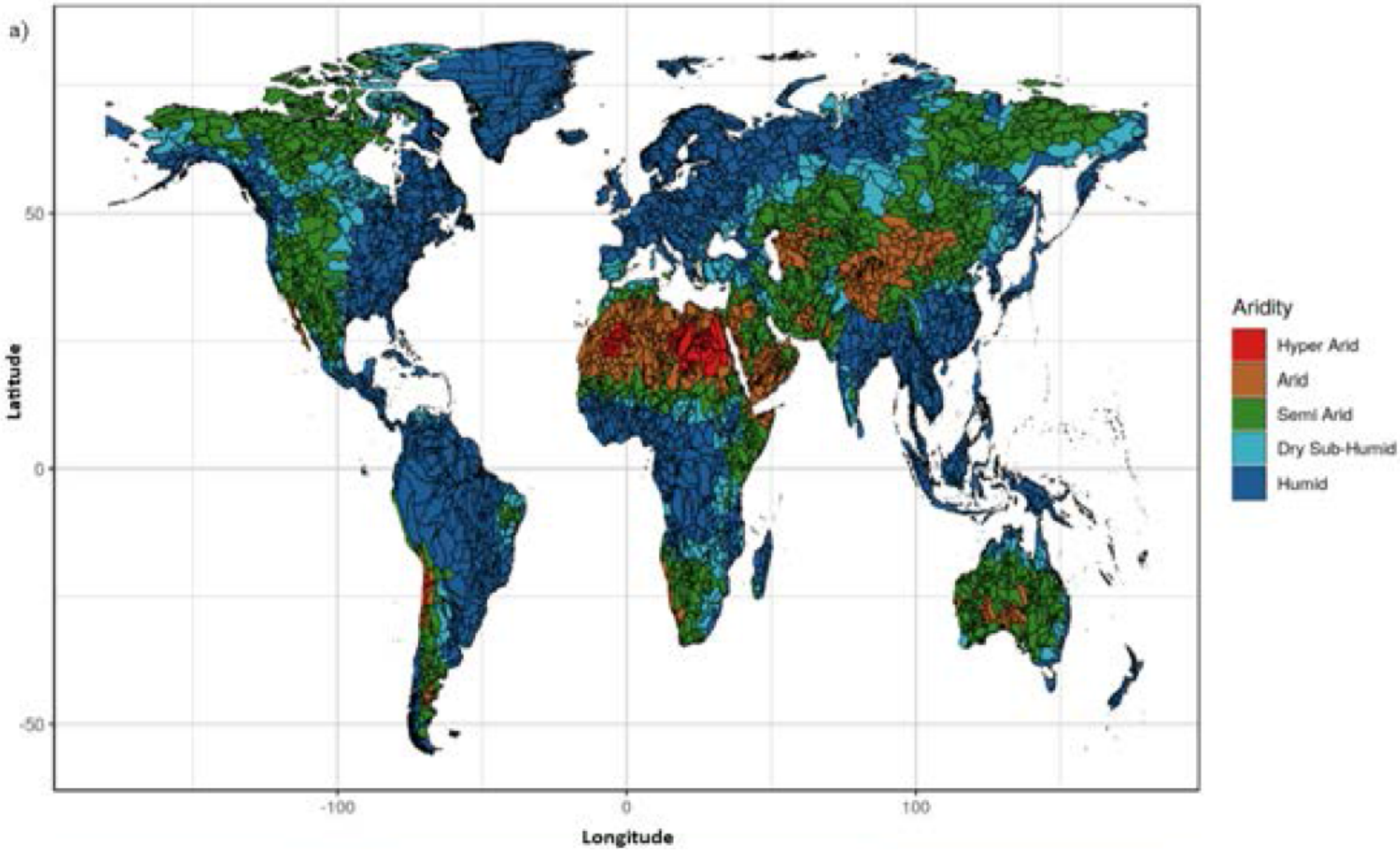


$$\frac{ET}{P} = 1 + \frac{PET}{P} - \left(1 + \left(\frac{PET}{P}\right)^{\omega}\right)^{\frac{1}{\omega}}$$

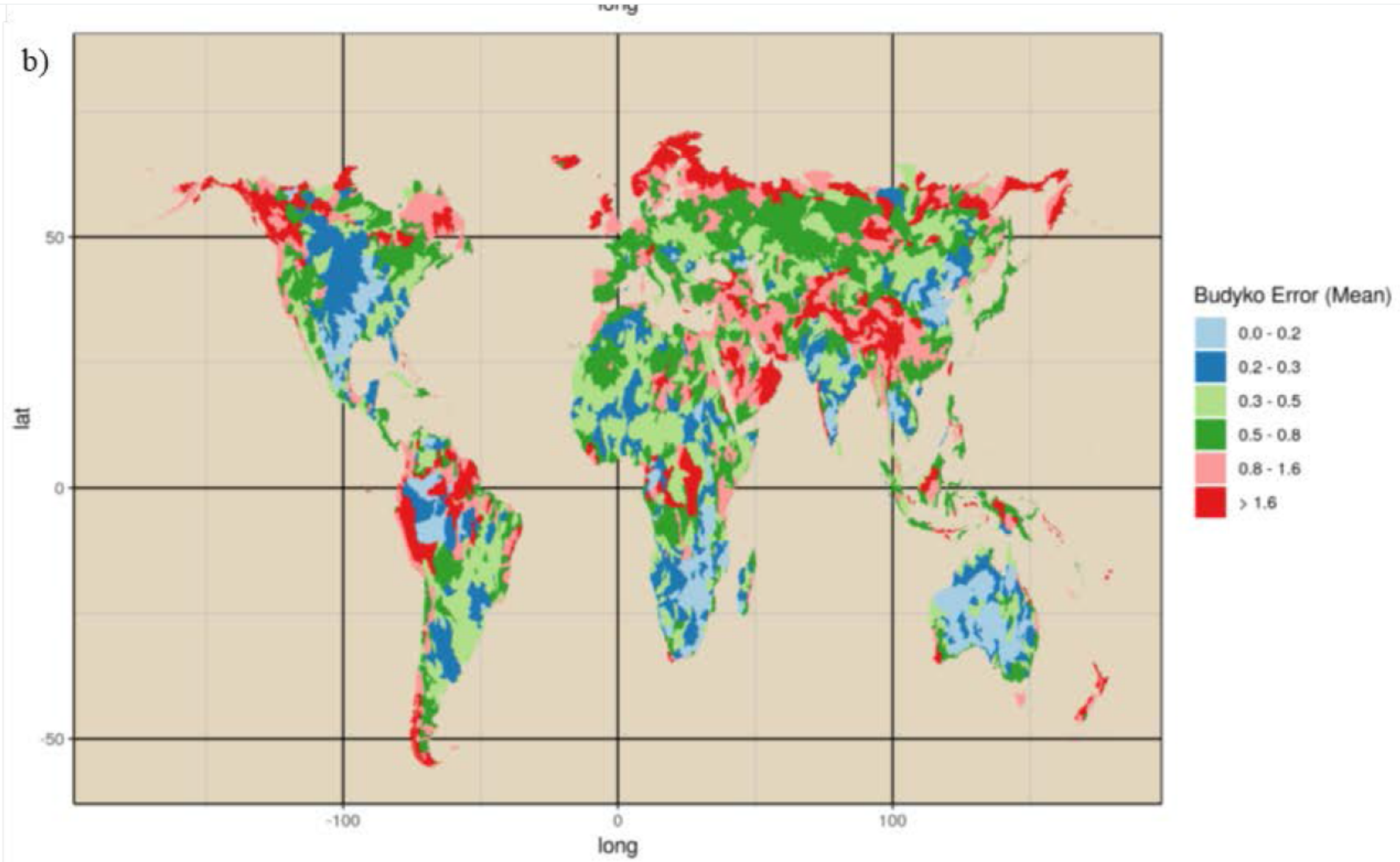
$$\frac{ET}{P} = 1, \qquad \frac{PET}{P} > 1 \qquad (water\ limit)$$

$$\frac{ET}{P} = \frac{PET}{P}, \qquad \frac{PET}{P} < 1 \qquad (energy\ limit)$$

a)

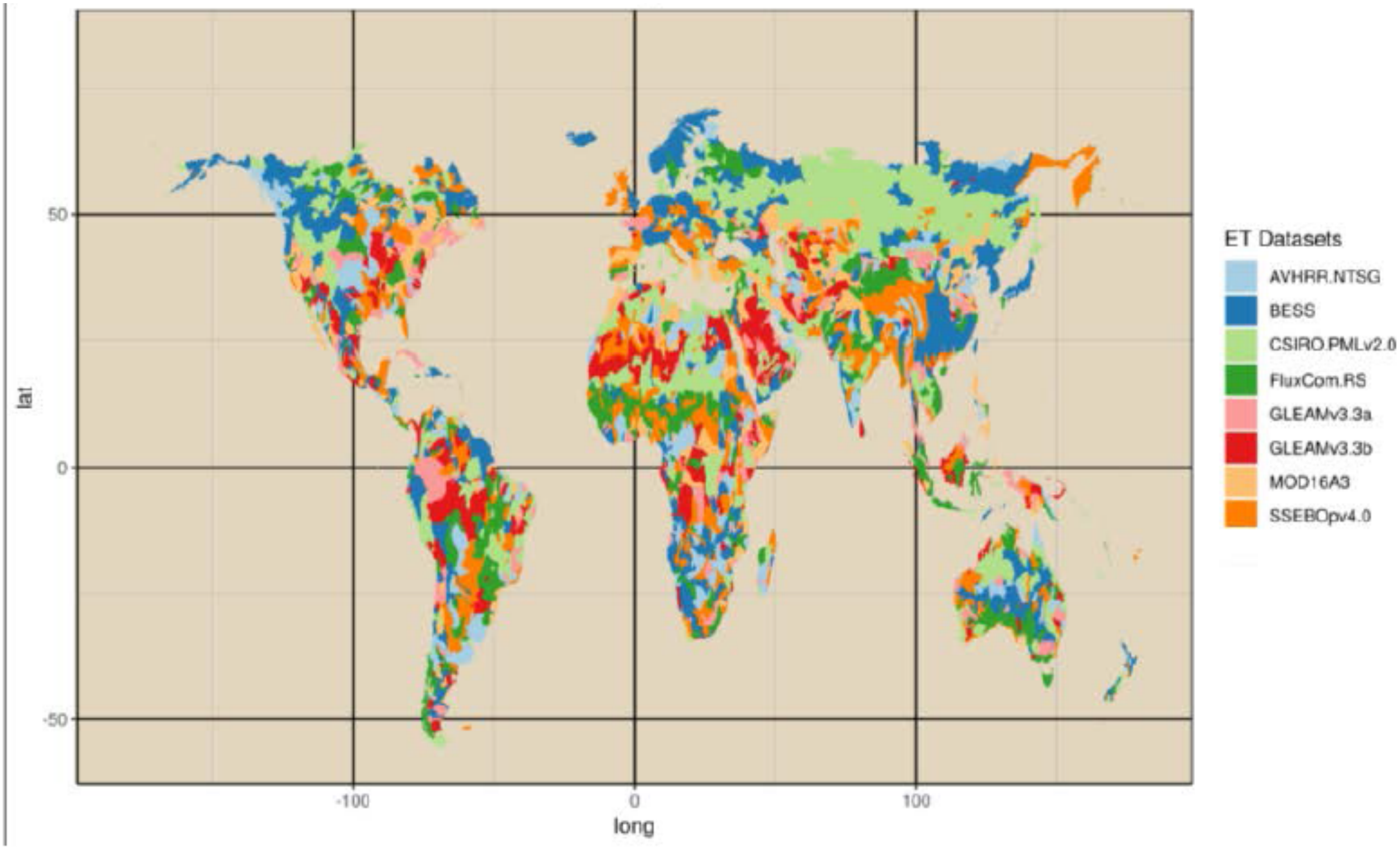


Latitude
50
0
-50
-100
0
100
Longitude
Aridity
Hyper Arid
Arid
Semi Arid
Dry Sub-Humid
Humid



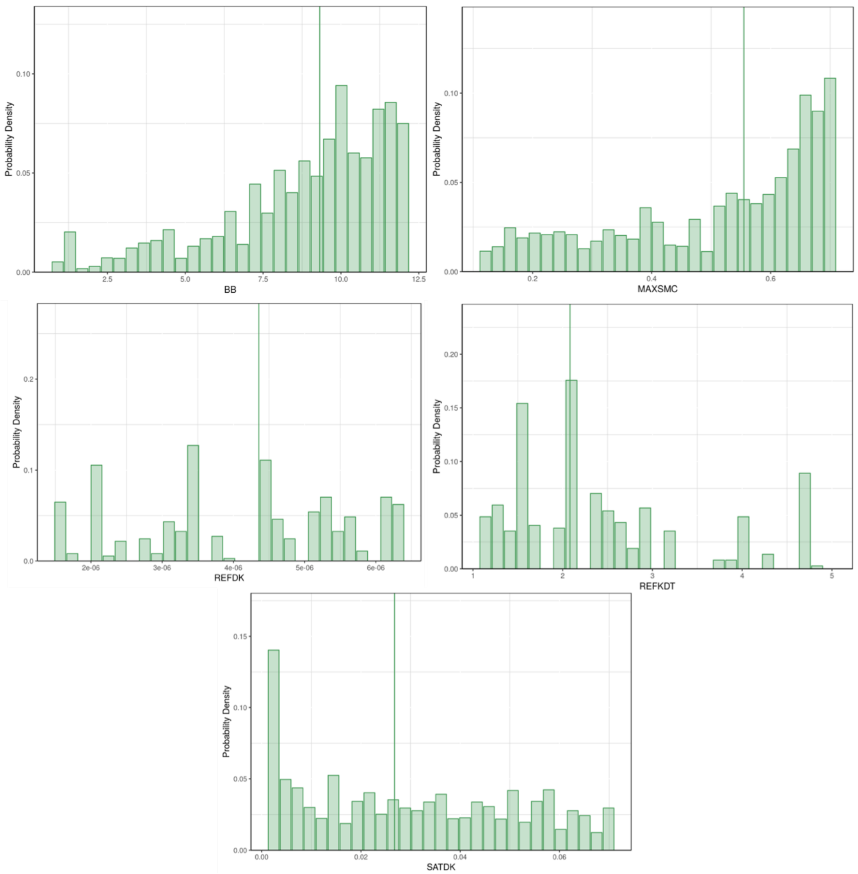
Global distribution of the mean of a) cluster radii and b) Budyko errors, normalized by the aridity index of catchments, determined using 64 combinations of P, ET, and R_n datasets.

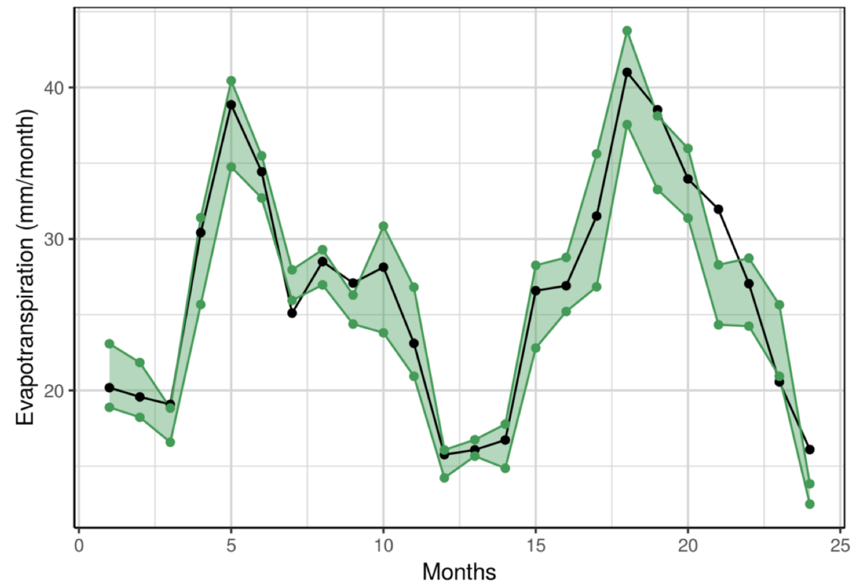
Best ET products for different parts of the world



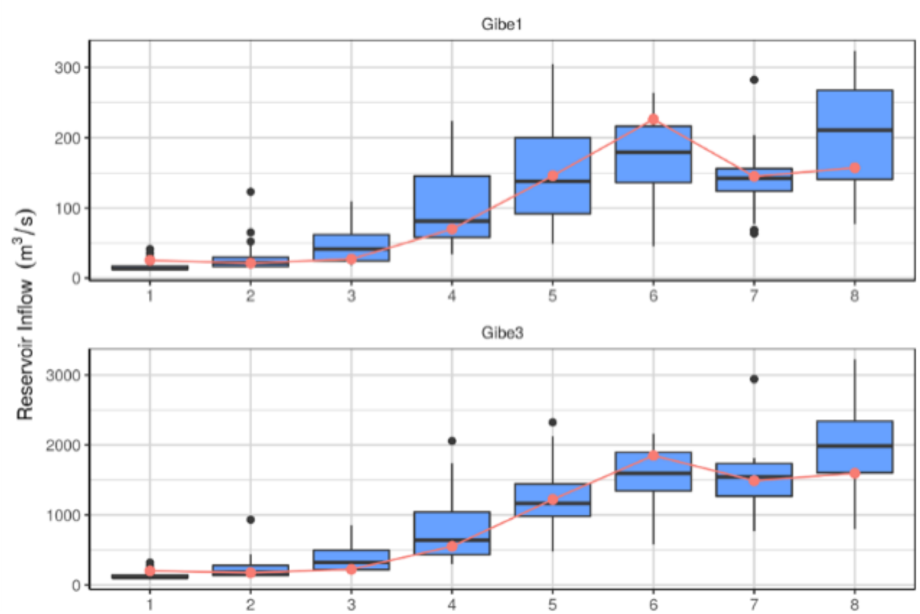
Validation of the Noah-MP Model using best ET

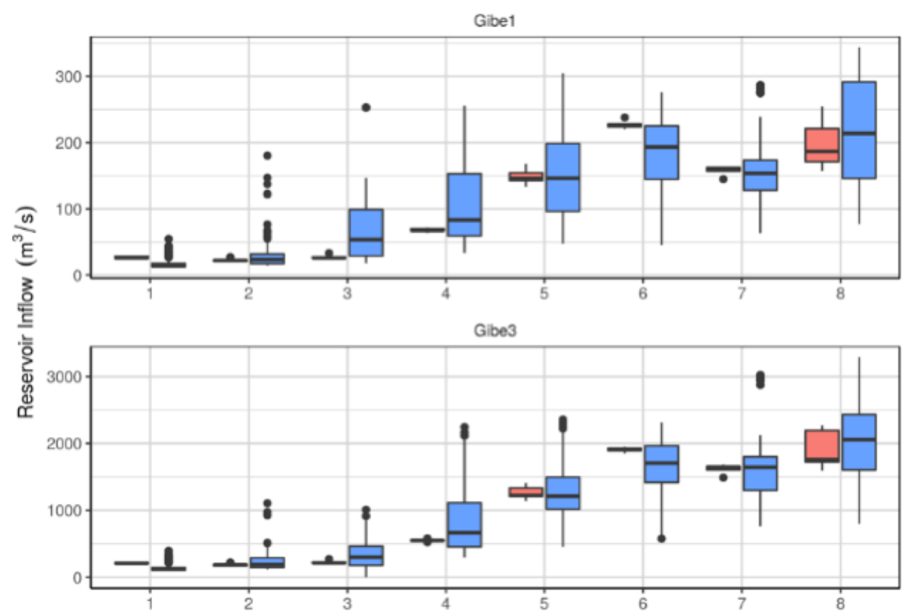
Posterior Distribution of Model Parameters





Reservoir Inflow Forecasts





Without Parameter Uncertainty **With Parameter Uncertainty**

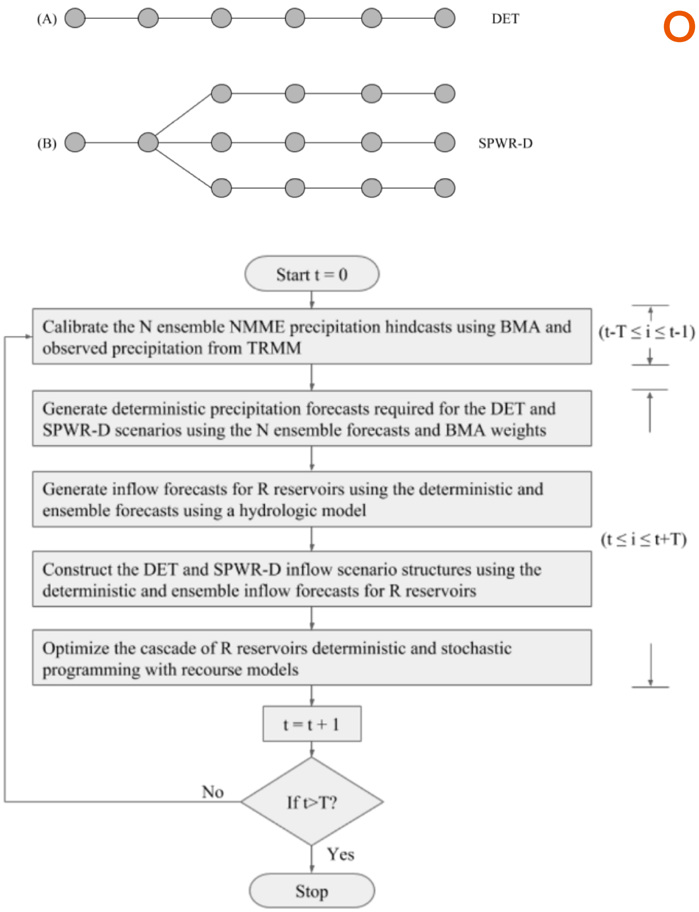
Methodology

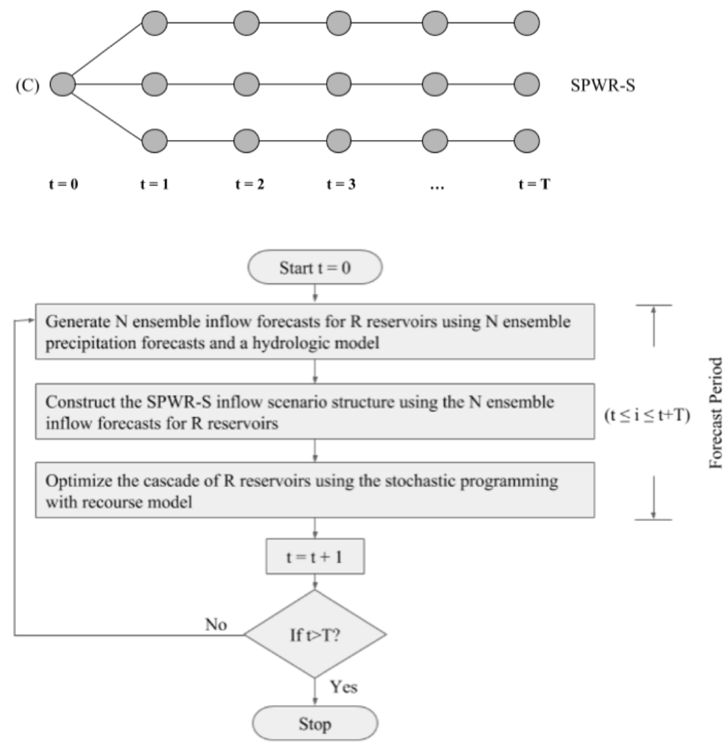
- **Task 3: Implement a coupled monthly, weekly and daily multi - objective reservoir optimization model to generate optimal release decisions for various purposes with different levels of priority based on the needs of the stakeholders**

Tasks

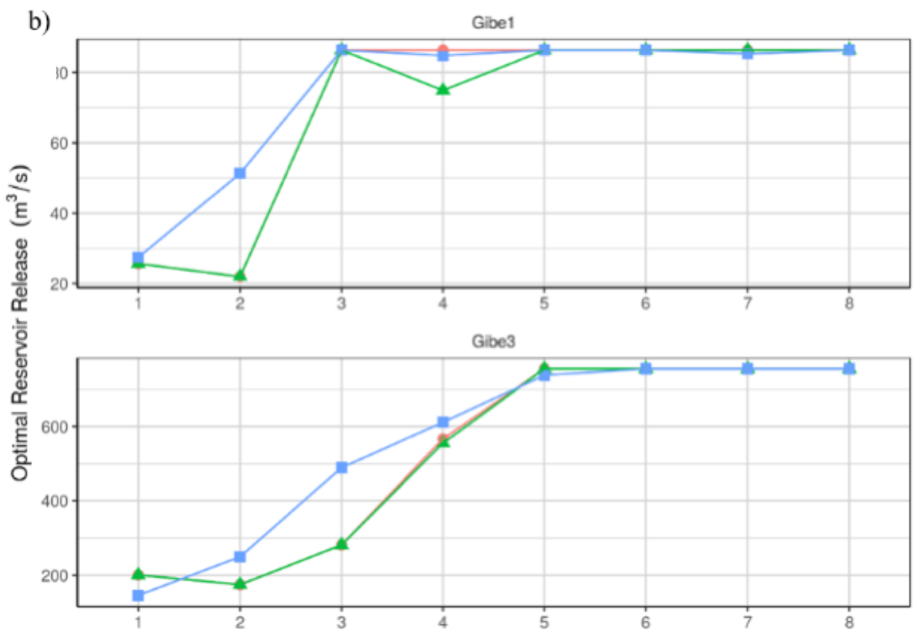
- Develop a new methodology for optimization

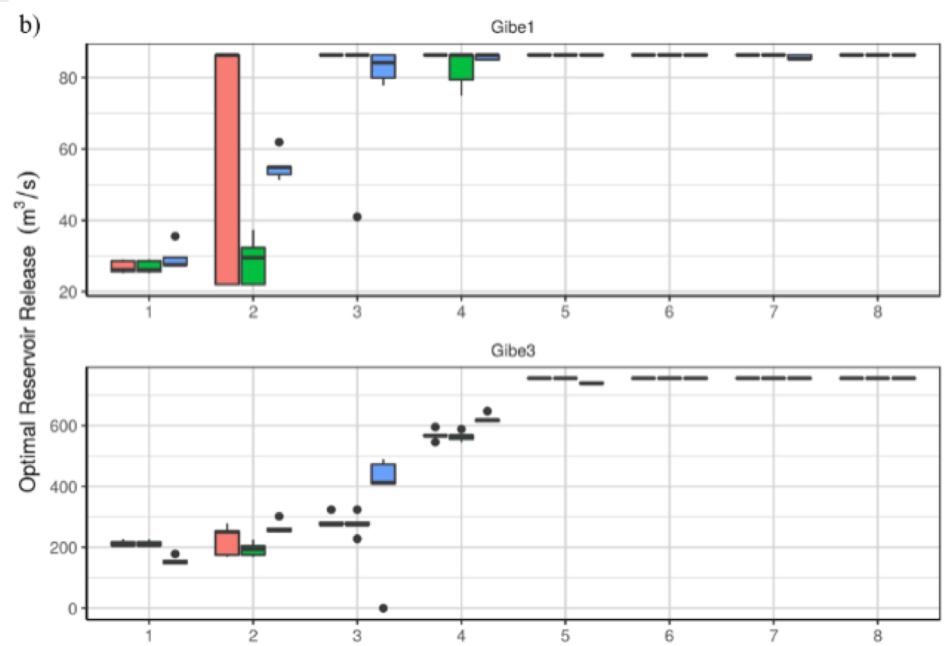
Optimization





Optimization System - Optimized Release Decisions





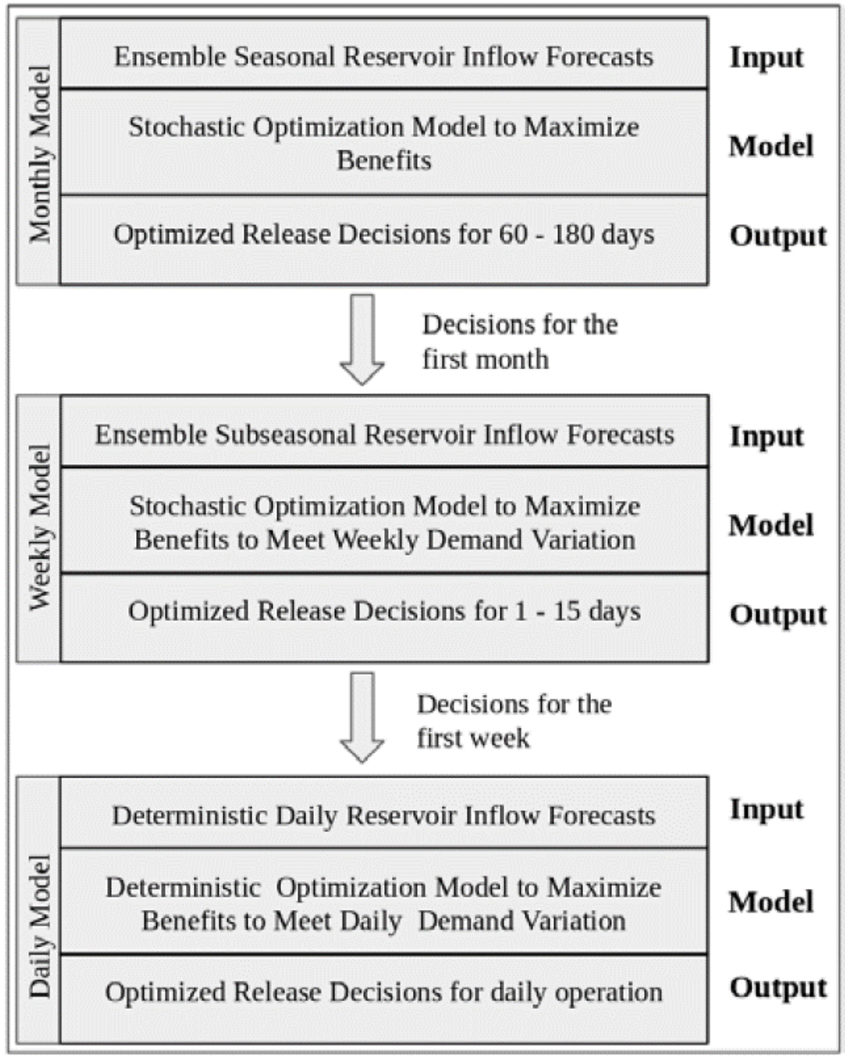
Without Parameter Uncertainty

With Parameter Uncertainty

Scenario
- DET
- SPWR-D
- SPWR-S

Power Production:

- **Actual - 750 MW**
- **SPWR-D - 994 MW,**
- **DET - 1014 MW**
- **SPWR-S - 1060 MW**


Monthly Model
Ensemble Seasonal Reservoir Inflow Forecasts
Input
Stochastic Optimization Model to Maximize Benefits
Model
Optimized Release Decisions for 60 - 180 days
Output
Decisions for the first month
Weekly Model
Ensemble Subseasonal Reservoir Inflow Forecasts
Input
Stochastic Optimization Model to Maximize Benefits to Meet Weekly Demand Variation
Model
Optimized Release Decisions for 1 - 15 days
Output
Decisions for the first week
Daily Model
Deterministic Daily Reservoir Inflow Forecasts
Input
Deterministic Optimization Model to Maximize Benefits to Meet Daily Demand Variation
Model
Optimized Release Decisions for daily operation
Output

Acknowledgement:
Funding support from the NASA PMM

Gibe III – tallest dam in Africa